Projectq title: Control strategies for space debris removal: evaluating MPC vs. PID with potential field approach

Authors:

Davide Nascivera / davnas@kth.se

Lorenzo Fici / fici@kth.se

Allocation of responsibilities

Davide Nascivera and Lorenzo Fici will both be responsible for the full project.

Organisation

The project will be organised as a two-person project.

Background

The usage of satellite technology in our days is increasingly relevant to the development of new products. Since the late 1950s, with the starting with the Sputnik satellite in 1957. Since then, the number of artificial satellites has ballooned up to the tens of thousands, vastly increasing the amount of human activity in our orbital highways. This has resulted in significant orbital debris and light pollution in our night skies. A couple of amazing bites have covered these two problems (orbital debris, light pollution, also light pollution).[1]

Problem statement

Is an essential challenge managing space debris both the big ones and the small ones.

Scientific models estimate the total number of space debris objects in Earth orbit to be in the order of:

- 29,000 - for sizes larger than 10 cm
- 670,000 - for sizes larger than 1 cm
- More than 170 million - for sizes larger than 1 mm.

Any of these objects can cause harm to an operational spacecraft.[2]

Problem

The project will focus on analysing and comparing two different types of controllers: the Model Predictive Control (MPC) and the PID controller integrated with potential fields for path planning. The main objective will be to determine which of the two systems offers better performance, based on a number of key metrics, including:

- Computational complexity
- Fuel consumption

This evaluation will be conducted through extensive testing and simulations to highlight the strengths and limitations of each approach. The results will help provide a solid basis for choosing the most suitable controller in specific application contexts.

Hypothesis

We think that despite the increased computational need, MPC (Model Predictive Control) still manages to provide superior performance in trajectory efficiency, especially in fuel consumption. MPC can actually outperform PID, which is faster in calculating a trajectory but often less efficient in optimising overall energy consumption. Because of its ability to plredict and optimise the trajectory over a time horizon, the MPC

proves to be a more advantageous choice when efficiency is a critical factor.

Purpose

The objective is to compare different control techniques for managing agents in charge of dismantling an unidentified vehicle (space debris). Through simulation, we will evaluate which control method is most effective in ensuring accuracy, efficiency in resource consumption, and speed of execution. This comparison will identify the best approach for operating in complex scenarios such as space debris removal, where accuracy and resource optimization are crucial to mission success.

Goal(s)

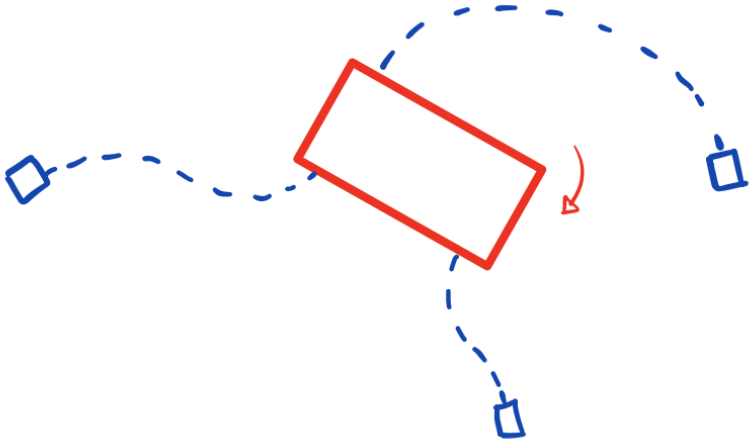
Test the hypothesis to determine which controller is better against several metrics, paying particular attention to sustainability. Specifically, we want to evaluate:
- the time required to perform the task;
- the hardware required (silicon and attached microprocessor);
- the fuel or energy required to complete the task.

Tasks:

To simulate and evaluate all the KPI listed in the paragraph above, we will design and develop the following simulation environment:

- a rigid body, simplified as the red rectangle that rotates and translate in the plane following its own dynamics
- one or more agent that has to move in specific position and attitude on the surface of the rigidbody

The simulation will be performed on python using standard libraries such as cvxpy, control etc. The environment will allow analysis and comparison of the performance of different controllers against the defined metrics.



Method

The project will be based on existing literature about the topic of MPC in collision avoidance. We will also reuse and modify an existing model for spatial objects used in the MPC course. Furthermore we'll use examples of code online for setting up the environment where we'll do additional experiments.

Milestone chart (time schedule)

The project will start on 17 September after submitting the project proposal.

24 September: Discussion research plan, UML draft and environment setup for simulation

1 October: Consolidate sustainability considerations and creating working toy example with unicycle simplified model without MPC with target object not rotating

8 October: First draft of research plan, reflection on ethics and sustainability, presentation, and peer reviewing.

29 October: Mpc implementation for object not rotating and toy example with real agent model

11 November: Target object now rotating for both approach

25 November: First draft report and presentation

5 December: Multi agent system

12 December: Collision avoidance implementation

19 December: Provide the current version of Final Report Draft to opponents

7 January: Written opposition report - for teacher feedback

7 January: Written opposition report - as feedback to peers

10 January: Final seminar - with oral opposition

17 January: Final report

References

[1] O'Callaghan J. (2023). *What is space junk and why is it a problem?* https://www.nhm.ac.uk/discover/what-is-space-junk-and-why-is-it-a-problem.html

[2] European Space Agency. (n.d.). *How many space debris objects are currently in orbit?*

https://www.esa.int/Space_Safety/Clean_Space/How_many_space_debris_objects_are_currently_in_orbit